Numerical Study on River Embankment Failure due to Overtopping Flow Considering Infiltration Effects

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1. INTRODUCTION

Recent climate change will lead to an increase in heavy rainfall events and the occurrence of river water level rise, which exceeds the design, is increasing. Therefore, reinforcement of river embankments plays a larger role in disaster prevention than ever before. Development of a numerical model that can reproduce the embankment erosion phenomenon, which is a majority event causing embankment failure, is required to investigate countermeasures against erosion due to overtopping flow. In particular, it is important and required that the numerical model which can reproduce the temporal failure process of river embankments.

Many experimental studies and several numerical simulations have been conducted on the phenomenon of embankment failure due to overtopping flow. However, some problems remain with predictions using the existing numerical models. The accuracy of the simulation results of existing embankment failure models are inadequate for a simulation tool to make predictions and to consider countermeasures. In particular, the numerical models could not reproduce sufficiently the time variations in the shape of embankments. The main goal of this research is to develop a new numerical model that can compute the river embankment erosion process while considering the infiltration effects in surface erosion without adjusting the coefficients related to erosion rate.

2. NUMERICAL SIMULATION OF EMBANKMENT EROSION DUE TO OVERTOPPING FLOW

In this study, a numerical model for predicting erosion due to overtopping flow at a river embankment has been developed by combining four modules, i.e., seepage flow, surface flow, sediment transport, and slope failure. The highlight of the present model is the estimation of the erosion rate considering the effect of saturation conditions on the embankment surface, which is calculated in the seepage flow model.

On the back slope of an embankment, infiltration and erosion processes occur quasi-simultaneously due to overtopping flow. In addition, the erosion process due to overtopping flow is repetitive erosion of the saturated layer and the unsaturated soil because of the continuous progress of surface infiltration. **Figure 1** shows the state of the experiments on embankment erosion from overtopping flow. As we saw from these photos, the progress of the wetting-front and erosion processes occurred quasi-simultaneously because of overtopping flow on the back slope. The erosion occurred just after the decrease in shear strength due to suction, which was caused by a change in the soil condition from unsaturated to saturated condition. Thus, taking into account the processes of seepage flow processes, variation in shear strength due to suction, and the erosion rate for a saturated surface soil and for an unsaturated soil below the saturated layer in a numerical model is important to simulate the erosion process on unsaturated soils due to overtopping flow.

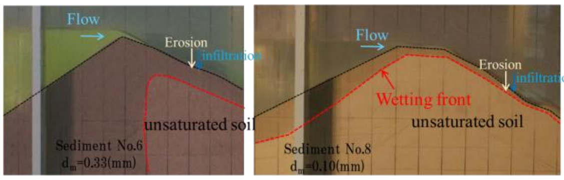


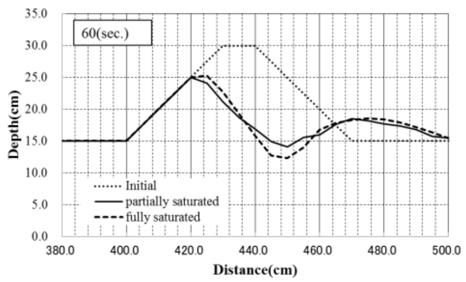
Fig. 1 Infiltration process prior to flow overtopping.

This study attempted to develop a new model for the surface erosion process, which is a repetition of the erosion of saturated and unsaturated soil and surface infiltration. The saturated layer existed, at least thinly, on the surface layer due to continuous infiltration of the overtopping flow, and unsaturated soil is below the saturated layer. The saturated layer is eroded first, the unsaturated soil is eroded next, and infiltration occurs next. To simulate the process of this erosion and infiltration cycle, two pickup rate formulae were used in both saturated and unsaturated conditions as a new approach.

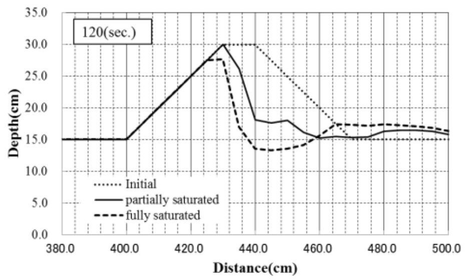
3. LABORATORY EXPERIMENTS AND NUMERICAL SIMULATION

3.1. Experimental Results

A series of flume experiments were carried out to investigate the erosion mechanism of a river embankment. In this study, discussions of the experiments focus on the influence of the differences in saturation of the embankment body for the erosion due to overtopping flow. **Figure 2** shows an example of comparisons of the experimental results of embankment shapes on erosion process under different initial saturation conditions. These experiments showed that the degree of shear strength due to suction and the required time to change into saturated condition on the embankment surface, i.e., infiltration process of the embankment surface, are important factors for estimating the erosion rate on unsaturated soils. These results suggest that considering the infiltration of water inside the dam is one approach to improve the erosion process in the numerical simulation.



(a) Sediment No.7 (d_m=0.17mm)



(b) Sediment No.8 (d_m=0.10mm)

Fig. 2 Comparison of experimental results under different initial saturation conditions

3.2. Simulation Results

A numerical simulation of laboratory experiments on embankment erosion was conducted using the developed numerical model. **Figure 3** shows an example of comparison of simulated and experimental results. The simulated results of the temporal variation of embankment shapes were well reproduced by the present numerical model.

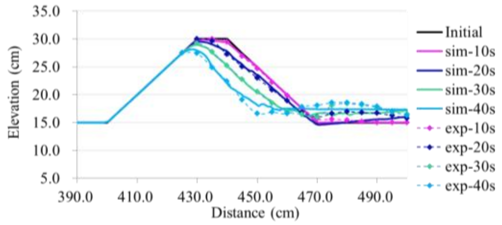


Fig. 3 Simulated and experimental results.

4. CONCLUSIONS

The erosion process of a river embankment from the non-cohesive fine sediment was investigated through laboratory experiments and a numerical model.

The experimental results for the embankment made by non-cohesive fine sediments showed that the erosion rate in small-sized sediment is lower compared with larger-sized sediment. In the embankment of small-sized sediment, shear strength due to suction is responsible for the lower erosion rate. We observed that the erosion of unsaturated embankment was highly influenced by the suction in unsaturated soil because the matric suction increases the shear strength. In addition, the conditions of the saturation and infiltration rate in the embankment also cause a difference in the erosion rate of the unsaturated embankment. Therefore, the shear strength due to suction and infiltration from overtopping flow plays vital role in the erosion of a non-cohesive homogeneous river embankment.

An embankment erosion numerical model is developed using combined depth average flow, seepage flow, and a sediment transport model based on a non-equilibrium model and a slope stability model. In this study, a new expression for resisting shear strength due to suction was derived in pick-up formula to compute the erosion of unsaturated river embankment by overtopping flow. We used a pick-up formula based on both saturated and unsaturated conditions to simulate the erosion process of the embankment surface that occurs simultaneously with infiltration. The proposed model was tested for erosion of the embankment under different sediment sizes conditions. Generally, the present numerical model well reproduced the processes of embankment surface erosion due to overtopping flow.

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